LA-UR -84-1680

LA-UR--84-1680

DE85 008629

TITLE: PROGRESS REPORT ON THE ESTABLISHMENT OF A METHODOLOGY FOR PREDICTING LIFETIMES IN ACTIVE SOLAR SYSTEMS

AUTHOR(S): John G. Avery

NO DT

MASTER

SUBMITTED TO: Solar Energy Research Program Review Meeting
Golden, Colorado
Spring, 1984

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

PROGRESS REPORT ON THE ESTABLISHMENT OF A METHODOLOGY FOR PREDICTING LIFETIMES IN ACTIVE SOLAR SYSTEMS*

by

John G. Avery
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

Real-time field site and accelerated laboratory data have been generated for five commercially significant metal/fluid combinations found in active solar systems.

I. SUMMARY

Five active field sites have been chosen with the following metal/fluid combinations:

1. Copper/uninhibited, degraded propylene glycol,
2. Aluminum/uninhibited, degraded propylene glycol,
3. Copper/inhibited ethylene glycol (high-temperature absorption cooling),
4. 444 stainless steel/water, and
5. Copper/inhibited propylene glycol [medium temperature domestic hot water (DHW)].

*Work performed under the auspices of the US Department of Energy, Office of Solar Heat Technologies.

Corrosion data, fluid data, and operating data have been collected at the above sites. Accelerated laboratory corrosion tests have been completed on the metal/fluid combinations listed above.

II. INTRODUCTION

Three factors enter into the life-cycle cost of active solar systems: system efficiency, cost, and lifetime. Of the three, lifetime has been the most difficult to quantify because of the times involved in real-time testing.

Because corrosion is one of the main factors that governs active solar system lifetime, and because much laboratory-generated corrosion data exists, Los Alamos initiated work in 1982 to develop a methodology for predicting active solar lifetimes using real-time field data collected over a relatively short (1-2 yr) time period. In addition, accelerated testing similar to the proposed American Society for Testing Materials (ASTM) method was performed using the metal/fluid combinations found in the field sites that were monitored.

Last fiscal year we developed an inexpensive, automated, data collection system, and installed the data system and corrosion samples in field sites that have the commercially most significant metal/fluid combinations. Additionally, we developed methodology to compare limited field data with the much larger amount of laboratory data. This may, in the future, permit prediction of actual lifetimes from laboratory data.

The progress of this work in FY-1983 is described in the following two sections.

III. FIELD-SITE DATA

A. Field Sites Established

The following field sites were chosen as they provide a good representation of the commercially significant metal/fluid combinations.

1. Los Alamos Solar Laboratory Site No. 1. This site is a closed system using a copper collector and plumbing with a fluid of uninhibited degraded propylene glycol. This system has been running since July 1982, and the first samples have been analyzed.

2. Los Alamos Solar Laboratory Site No. 2. This site is a closed system using an aluminum collector and copper plumbing with uninhibited degraded propylene glycol fluid. This system started operation in October 1982.

3. Central Solar Plant, Ft. Polk, Louisiana. This system provides heating and cooling for 40 family housing units. It consists of 8400 ft^2 of evacuated tube collectors (General Electric TC-100®) in a closed system with a heat transfer fluid of 20% inhibited ethylene glycol (Prestone II®) and water in copper plumbing and collectors. Samples have been in place since August 1982.

4. Bachelor Officers Quarters, Nellis Air Force Base, Las Vegas, Nevada. This is a DHW system where the collectors (600 ft^2) are Type 444 stainless steel with copper piping. The fluid is domestic water with freeze protection provided by recirculation. Samples have been in place since July 1982.

5. Los Alamos Support Office Building. This is a domestic hot water (DHW) system with 3000 ft^2 of collector. The system is closed and uses a heat transfer fluid of 50% inhibited propylene glycol (Dowfrost®) and 50% water with copper plumbing and collectors. Samples have been in place since February 1982.

Sites 1 and 2 fulfill two needs.

1. The higher corrosion rates will allow collection of field data over a shorter time than would systems with good fluid.

2. The rate of corrosion in systems with degraded fluid must be determined, as this dictates the fluid-maintenance schedule.

B. Details of Field Testing

The particulars of the field testing are as follows:

1. Specimen preparation. Samples for the sites requiring copper are made from 5/8-in. o.d. Type L copper water tube. One-inch-long samples are cut, deburred, and stamped, after which they are cleaned with acetone; the original surface is utilized. Each sample weight is recorded to the nearest 0.1 mg. Aluminum samples are machined from 1100 cold drawn bar into 5/8-in. o.d., 1/16-in. wall, 1-in.-long samples. Samples of 444 stainless steel were cut from a new collector. The sample was sheet metal expanded into an X with the seam weld at the intersection of the legs. All samples are mounted in Teflon holders; some samples are surrounded by a Teflon ring with 0.005-in. clearance to allow crevice corrosion.

2. Test apparatus.

a. Test manifold. Samples are secured in a bypass manifold attached atop a collector bank in each of the field sites. Flow is rerouted through the bypass; removal of the blind flange permits retrieval of samples without shutting the system down.

b. Test cycle. The operating parameters of the system relevant to corrosion are fluid condition and fluid temperature. Fluid condition is monitored by taking fluid samples periodically, and fluid temperature is monitored by a thermocouple probe in the manifold. Additionally, the system is monitored to determine if it is actually operating. Comparison of temperature and operational condition of the system allow determination of any periods of stagnation. The operating data is integrated to provide total time in various temperature regimes. The automated data collection system used to perform the above-mentioned tasks is described in Sec. C.

3. Specimen evaluation.

a. Weight-loss determinations. As corrosion coupons are received from the field, the scale is removed and treated in a manner prescribed in ASTM Standard Practice 6-1.

C. Low-Cost Automated Data Collection

Collection of data from those field-systems' operating parameters that influence corrosion is desirable to assure the capability of quantifying corrosion in a manner to allow comparison of field tests with laboratory tests. The data-collection system used by Vitro Corporation in the National Solar Data Network (NSDN) could have been modified to meet these needs, but the basic expense of the system was prohibitive. No inexpensive systems were available on the market. For this reason, the Los Alamos National Laboratory Solar Energy Section of the Advanced Engineering Technology Group developed its own low-cost system.

The data-collection system consists of an Apple II® computer with 48k of memory, an A/D converter board, an 8-channel multiplexer, and a signal conditioning device. Inputs for temperatures, pump on/off, etc., are fed in as voltages and are amplified to allow greater accuracy; the analog signal is then converted to bits.

The software developed for this application reads the sensors every 15 seconds and an average for each 10-minute interval is stored in the computer. Every 24 hours the values in the computer are stored on a floppy disc. The data is collected from the field by replacing the data-collection disc periodically with a new disc containing the data-collection program.

The data discs sent in from the field are analyzed using a data-analysis program that integrates the data and prints it out in the following format:

time period (h)

time in temperature range (%) pump on (%)

$>|T_1 < T_2$

$>|T_2 < T_3$

$>|T_3 < T_4$, etc.

The total cost of this system is approximately $2500. The assembled unit is constructed in a package that serves both as a security device and a shipping container.

D. Field Site Data Collected

1. Los Alamos Laboratory Site No. 1. This site is a closed loop system using a copper collector and plumbing with a fluid of uninhibited degraded propylene glycol. Because the site is maintained and operated by the Solar Section, this site has experienced no downtime or data-collection problems. As Table I shows, no significant changes occurred in the fluid with the exception of iron and, to a minor degree, copper. Weight loss is detailed in Table II.

The corrosion rate for copper in this system contradicts the presently held concept that degraded glycol causes greatly increased corrosion of a magnitude to significantly shorten system life. Copper corrosion rate appears in Fig. 2. Figure 3 shows the operating data for this system. The high percentage of time the pump is off at operating temperatures occurred because no check valve was present to present thermosyphoning at night.

TABLE I

FLUID COMPOSITIONS OF DEGRADED PROPYLENE GLYCOL/COPPER
(WEST LOOP)

	1982		1983				
	Oct.	Dec.	Feb.	Apr.	June	Aug.	Oct.
Glycol Type	Propylene						
% glycol	53.0	56.7	50	59	59	59.1	59.1
pH	3.8	4.3	4.2	4.2	3.9	4.0	4.0
Reserve Alkalinity	0	0	0	0	0	0	0
Na ppm	1.4						
Cu ppm	<0.1	<0.1	0.58	0.84	0.12	0.35	<0.2
Fe ppm	0.3	0.6	196	217	268	275	278
Al ppm	<0.1						
B ppm	4.0						
P ppm	<0.1						
K ppm	5.3						
Cl^- ppm	3.5						

TABLE II

WEIGHT LOSS FOR TYPE L COPPER IN DHW SYSTEM CONTAINING
UNINHIBITED DEGRADED PROPYLENE GLYCOL (WEST LOOP)

Time (Days)	Weight Loss (mg/cm^2)
65	0.68
125	0.50
180	0.43
240	0.54
300	0.55
360	0.67
420	0.65

2. Los Alamos National Laboratory Site No. 2. This site is a closed loop system with an aluminum collector and copper plumbing using a fluid of uninhibited degraded propylene glycol. The site has been running since April 1983. As with site No. 1, local operation and maintenance have prevented any downtime on either the solar loop or the data-collection equipment.

The corrosion attack on this system is not uniform but is characterized by extensive pitting. Fluid, corrosion, and operating data can be seen on Tables III and IV and Figs. 4-6.

TABLE III

FLUID COMPOSITIONS OF DEGRADED PROPYLENE GLYCOL/ALUMINUM
(EAST LOOP)

	1983			
	April	June	Aug.	Oct.
Glycol Type	Propylene			
% Glycol	46	46	47	47.6
pH	4.0	4.1	4.1	4.1
Reserve Alkalinity	0	0	0	0
Na ppm	4			
Cu ppm	0.8	-	0.6	<0.2
Fe ppm	0.8	117	130	137
Al ppm	<0.1	<0.05	<0.05	<0.05
B ppm	2.0			
P ppm	<0.1			
K ppm	8.2			
Cl^- ppm	5.0			

TABLE IV

WEIGHT LOSS FOR 1100 ALUMINUM IN REAL SYSTEM CONTAINING
UNINHIBITED-DEGRADED PROPYLENE GLYCOL

Time (Days)	Weight Loss (mg/cm^2)
60	1.16
120	1.75
180	1.77

3. Central Solar Plant, Ft. Polk, Louisiana. This site is a closed loop system using copper plumbing and inhibited ethylene glycol. The evacuated tube collectors allow the heat transfer-fluid to reach 220°F. Table V shows the fluid composition at various time intervals at Ft. Polk; Table VI shows weight loss for the copper in the system. Figure 7 gives fluid data for the system, Fig. 8 shows the copper corrosion rate, and Fig. 9 shows the operating data.

TABLE V

FLUID COMPOSITIONS OF INHIBITED ETHYLENE GLYCOL/COPPER (FT. POLK)

	1982		1983	
	Aug.	Nov.	May	Nov.
Glycol Type	Ethylene			
% Glycol	15.9	16.0	17.1	18.1
pH	7.89	8.2	7.9	7.7
Reserve Alkalinity	2.1	2.1	2.2	1.9
Na ppm	439	339	422	494
Cu ppm	1.4	0.9	2.5	<0.02
Fe ppm	2.3	8.2	5.3	0.06
Al ppm	<0.05	<0.05	<0.1	<0.05
B ppm	135	100	159	83
P ppm	227	216	247	67
K ppm	46	88	58	50
Cl^- ppm	4.0	4.5	11	11

TABLE VI

WEIGHT LOSS FOR COPPER IN A HIGH-TEMPERATURE SYSTEM CONTAINING INHIBITED ETHYLENE GLYCOL (FT. POLK)

Time (Days)	Weight Loss (mg/cm^2)
120	0.507
240	0.512
450	0.593

4. Bachelor Officers' Quarters, Nellis AFB, Nevada. This system utilizes Type 444 stainless steel with copper plumbing; the fluid is domestic water. The water composition, shown in Table VII, has been calculated by use of the Ryznar Index to be neither scaling nor corrosive. Table VIII gives the stainless steel weight loss over the exposure period of 12 months; Fig. 10 shows the steel corrosion rate.

The operating data (Fig. 11) show that the system is running almost continuously. In August 1983 the system was shut down for modification to correct this as well as other problems.

TABLE VII

WATER COMPOSITION AT BOQ (NELLIS AFB)

Na ppm	27
Si ppm	2.4
Ca ppm	3.2
Mg ppm	32.7
Cl mg/l	9.8
TDS mg/l	624
Total hardness, mg/l; 143 (as $CaCO_3$)	
Bicarbonate, mg/l; 50 (as $CaCO_3$)	
Total alkalinity, mg/l; 75 (as $CaCO_3$)	
pH	8.2

TABLE VIII

WEIGHT LOSS FOR 444 STAINLESS STEEL/DOMESTIC WATER IN DHW SYSTEM (NELLIS BOQ)

Time (Days)	Weight Loss (mg/cm^2)
90	0.065
270	0.123
360	0.131

5. Los Alamos Support Office Building (Otowi). This system, using 3000 ft^2 of flat plate collectors to supply DHW, is a closed loop and utilizes a 50% mixture of inhibited propylene glycol and water with copper collectors and plumbing.

This system provides a good example of the reliability/maintainability problems that plague active systems. Corrosion samples were installed in February 1982; since that time, the system has lost its heat-transfer fluid three times because of various problems and has been nonoperational for almost 12 months. Occurring primarily from mid-1982 to mid-1983, such loss of fluid caused stagnation and necessitated replacement of the fluid. The loop is now running trouble free. Table IX describes the system's fluid composition; Table X shows the weight loss of copper in the Otowi Building system. Figure 12 contains fluid data on this copper/inhibited propylene glycol system and copper corrosion rate can be found in Fig. 13.

Figure 14 shows operating data for the system; some time in the stagnation region can be observed.

TABLE IX

FLUID COMPOSITION OF INHIBITED PROPYLENE GLYCOL IN LOS ALAMOS SUPPORT OFFICE BUILDING (OTOWI)

	1983	
	May	Nov.
Glycol Type		
% glycol	70.1	69
pH	8.5	8.5
Reserve Alkalinity ml/l	7.4	5.3
Na ppm	16	26
Cu ppm	1.5	2.1
Fe ppm	3	<0.5
Al ppm	<0.05	<0.05
B ppm	13.6	
P ppm	1477	658
K ppm	2184	1948
Cl^- ppm	1.0	1.0

TABLE X

WEIGHT LOSS FOR TYPE L COPPER IN DHW SYSTEM CONTAINING INHIBITED PROPYLENE GLYCOL (OTOWI)

Time (Days)	Weight Loss (mg/cm^2)
180	1.8

IV. ACCELERATED LABORATORY DATA

A. Details of Laboratory Testing

The particulars of the laboratory testing are discussed below. The laboratory testing was performed by Olin Metals Research Laboratory under DOE contract, and monitored by the Los Alamos Solar Energy Group. The metal/fluid combinations present in the field sites were tested by Olin; the technical details of the test are as follows.

1. Specimen preparation. Rectangular copper coupons were sheared from 0.76-mm (0.030-in.) gauge sheet of a 1/4 hard temper. Aluminum 1100 was similarly fabricated from sheet in an A-12 temper; steel was similarly fabricated from cold rolled stock. Test specimens were prepared utilizing a two-die stamping operation; determining specimen dimensions and securing hole locations are shown in Fig. 15. Metal surfaces and edges were lightly abraded with 600-grit silicon carbide paper to remove surface scratches and smeared metal. Identifying codes were stamped on specimens and actual surface areas measured. Test specimens were degreased and immersed in an inhibited 10 volume per cent (v/o) HCl solution to remove thermal- and air-formed oxides before initial weighing. After thorougn rinsing, test specimens were weighed to the nearest 0.01 mg.

2. Test cell. Test specimens were secured to slotted 2.54-cm- (1-in.) diam ceramic holders by use of copper wire pins. The slotted geometry was specifically selected to provide a crevice at the attachment site. The ceramic holders, in turn, were secured to a titanium shaft with copper wire pins. The titanium shaft was connected to a nylon cover with a stainless steel collar and bearing system.

With external gearing and drive motor, the shaft assemblies were rotated laterally through the heat-transfer liquids at a rate simulating field service conditions [metal-to-fluid speed of approximately 0.5 m/s (1.7 fps)]. To simulate draindown, a titanium tube was extended into a given test cell and connected externally to a plastic reservoir by silicone tubing. For the draindown-type liquids, fluid was transferred daily between the cell and reservoir. With the exception of simulated stagnation testing, specimens remained completely immersed in all nondraindown configurations for the 6-month test period.

3. Daily test cycle. Up to 20 individual test cells could be contained in a large, regulated temperature bath. With the use of a recorder-controller, the temperature of the bath went through a daily cycle similar to that shown in Fig. 16. Although this schedule approximates the thermal cycle of a flat plate collector, the selection of a 93°C (200°F) maximum daily temperature was intended to make the test slightly more aggressive than most current field applications. It should also be noted that the daily draindown (point Dj) and refill (point H) were only utilized for fluids with a freezing point above -4°C (25°F). Both the thermal and draindown cycles were repeated daily throughout the 6-month test duration.

4. Simulated stagnation. Every two weeks throughout the test, each shaft assembly (including the ceramic holders and wetted copper specimens) was placed in an autoclave and exposed to a 204°C (400°F) temperature for 4 hours. This procedure provided a simulated stagnation exposure for metal coupons with a thin liquid film. Bulk solutions did not undergo any simulated stagnation testing; however, severely degraded propylene glycol was included as one of the test fluids to allow comparison with field sites at Los Alamos using the same degraded fluid.

Figures 17 through 21 show the accelerated test results for copper/uninhibited degraded propylene glycol, aluminum/uninhibited degraded propylene glycol, copper/inhibited ethylene glycol, 444 stainless steel/water, and copper/inhibited propylene glycol, respectively.

V. 1984 CONTINUING WORK

In 1984 we are continuing to obtain data from most of the sites. Additionally, we have added a drainback active system that is generating data in the same manner as the sites reported on here.

For sites with already adequate field data, we will be analyzing the samples from both accelerated and field testing, comparing corrosion rates and mechanisms in the two types of tests, and determining the acceleration factors of the accelerated tests.

ACKNOWLEDGMENTS

The author wishes to thank Lee Dalton and Jim Hedstrom for development of hardware and software for data collection, Jose Tafoya for data gathering, Burl Ketchum for sample preparation, and Jan Sander for word processing.

FIGURE CAPTIONS

Fig. 1. Fluid data for copper/uninhibited degraded propylene glycol system.

Fig. 2. Copper corrosion rate in copper/uninhibited degraded glycol system.

Fig. 3. Operating data for copper/uninhibited degraded propylene glycol system.

Fig. 4. Fluid data for aluminum/uninhibited degraded propylene glycol system.

Fig. 5. Aluminum corrosion rate in aluminum/uninhibited degraded glycol system.

Fig. 6. Operating data for aluminum/uninhibited degraded propylene glycol system.

Fig. 7. Fluid data for copper/inhibited ethylene glycol system (Ft. Polk).

Fig. 8. Copper corrosion rate in inhibited ethylene glycol system (Ft. Polk).

Fig. 9. Operating data for copper/inhibited ethylene glycol system (Ft. Polk).

Fig. 10. 444 Stainless steel corrosion rate in domestic water system (Nellis BOQ).

Fig. 11. Operating data for 444 stainless steel/domestic water system (Nellis BOQ).

Fig. 12. Fluid data for copper/inhibited propylene glycol system (Otowi).

Fig. 13. Copper corrosion rate in inhibited propylene glycol system (Otowi).

Fig. 14. Operating data for copper inhibited propylene glycol system (Otowi).

Fig. 15. Simulated solar service test samples.

Fig. 16. Daily thermal cycle--simulated solar service test.

Fig. 17. Corrosion data of copper in uninhibited degraded propylene glycol in accelerated test.

Fig. 18. Corrosion rate of aluminum in uninhibited degraded propylene glycol in accelerated test.

Fig. 19. Corrosion rate for copper in inhibited ethylene glycol in accelerated test.

Fig. 20. Corrosion rate of 444 stainless steel in domestic water in accelerated test (Nellis AFB).

Fig. 21. Corrosion rate of copper in inhibited propylene glycol in accelerated test.

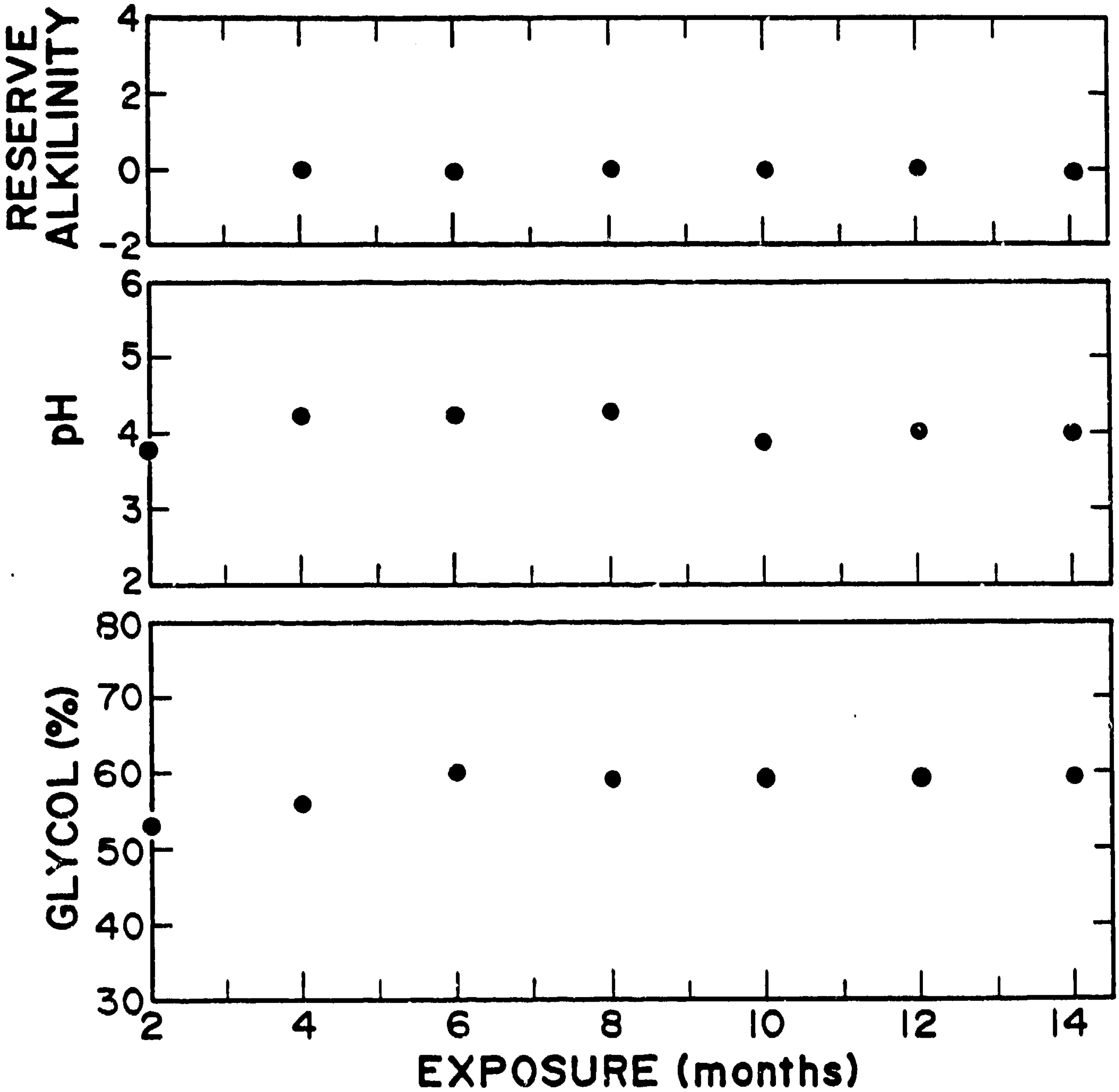

Fig. 1. Fluid data for copper/uninhibited-degraded propylene glycol system

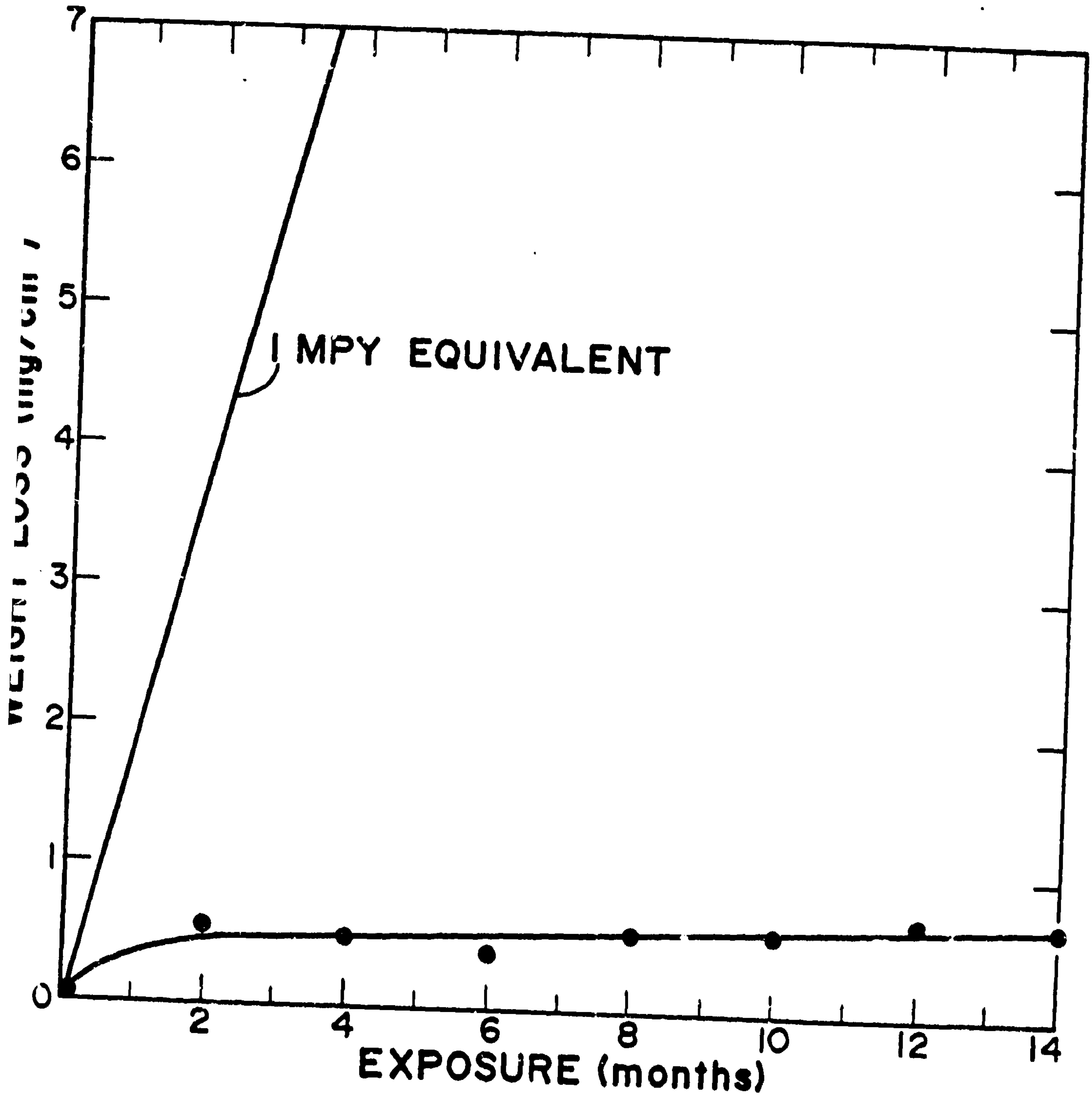

Fig. 2. Copper corrosion ratio in copper/uninhibited-degraded glycol system

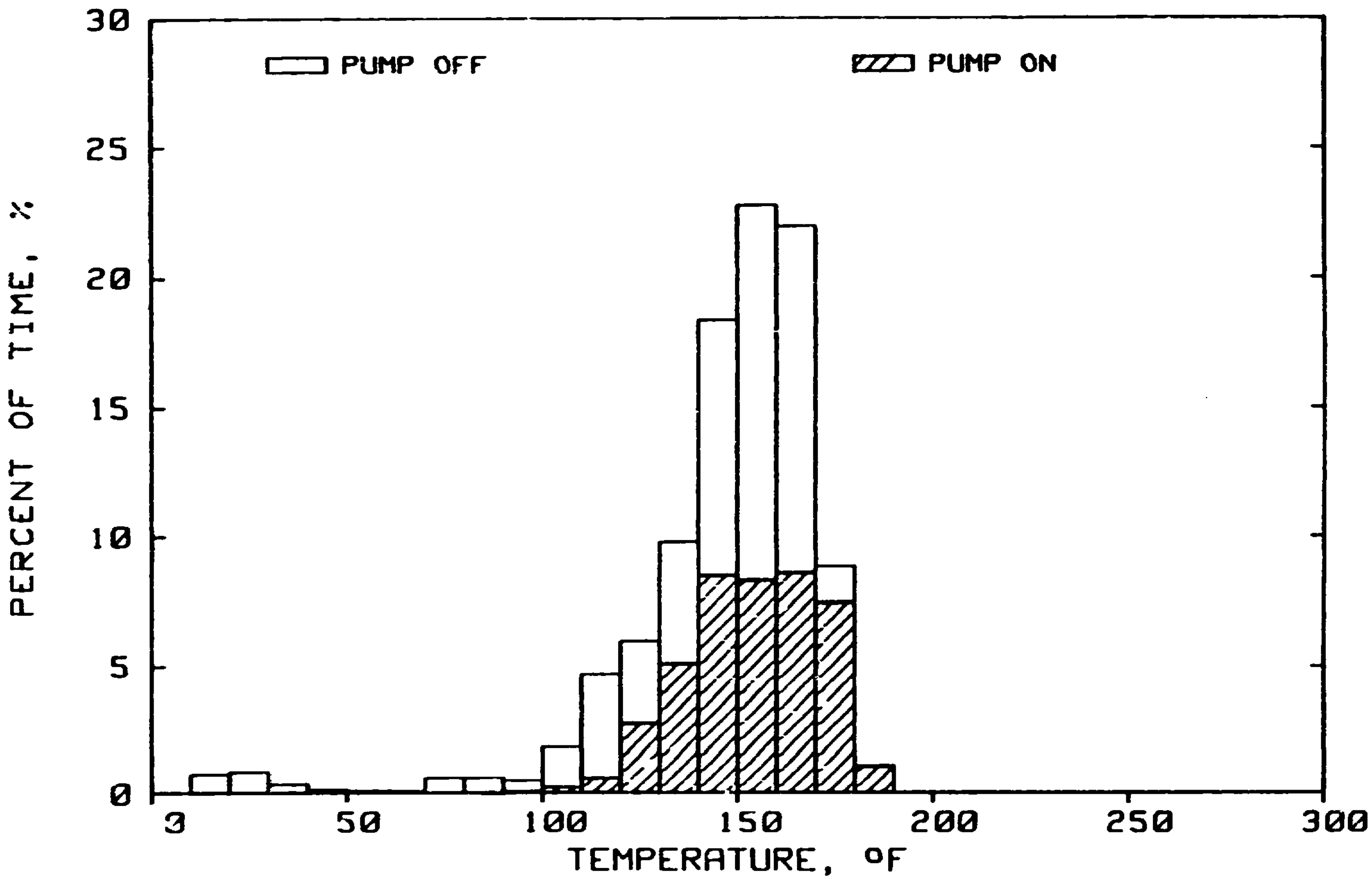

Fig. 3. Operating data for copper/uninhibited-degraded propylene glycol system

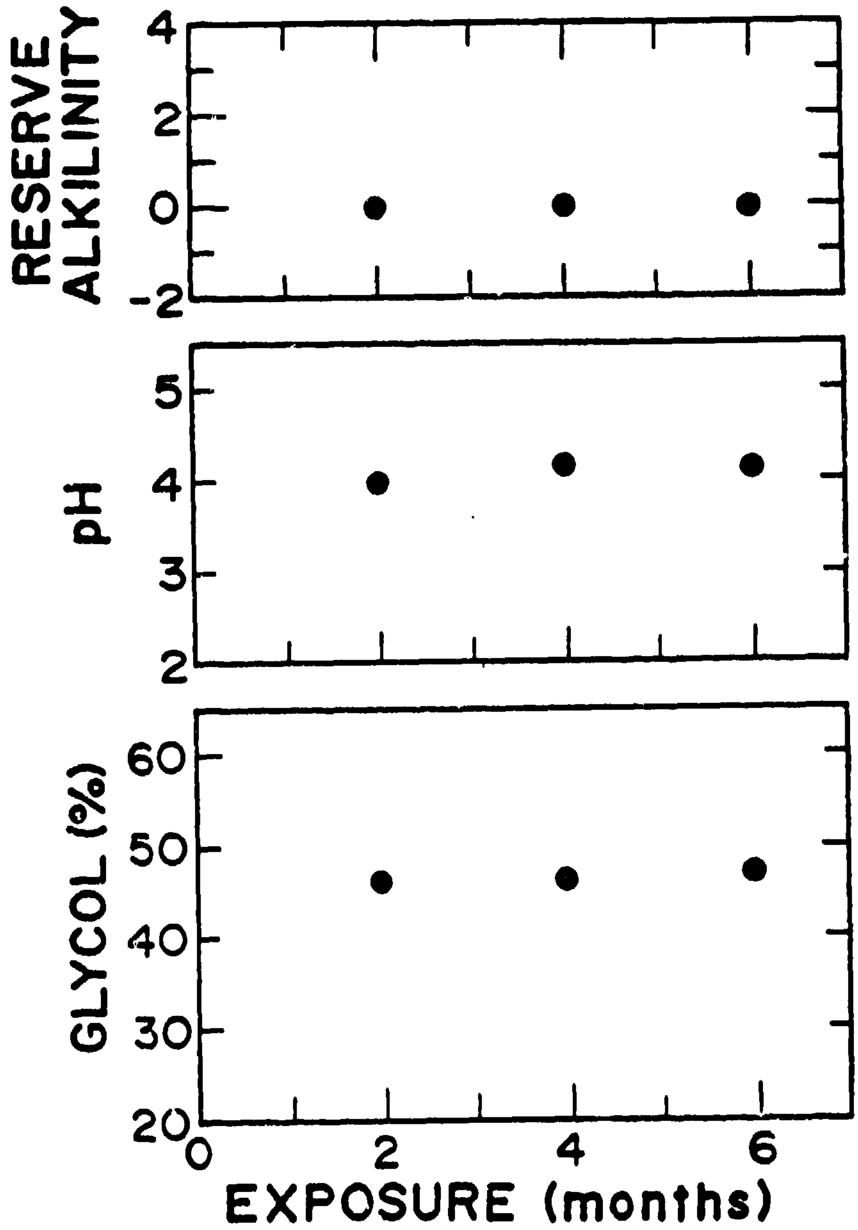

Fig. 4. Fluid data for aluminum/uninhibited-degraded propylene glycol system

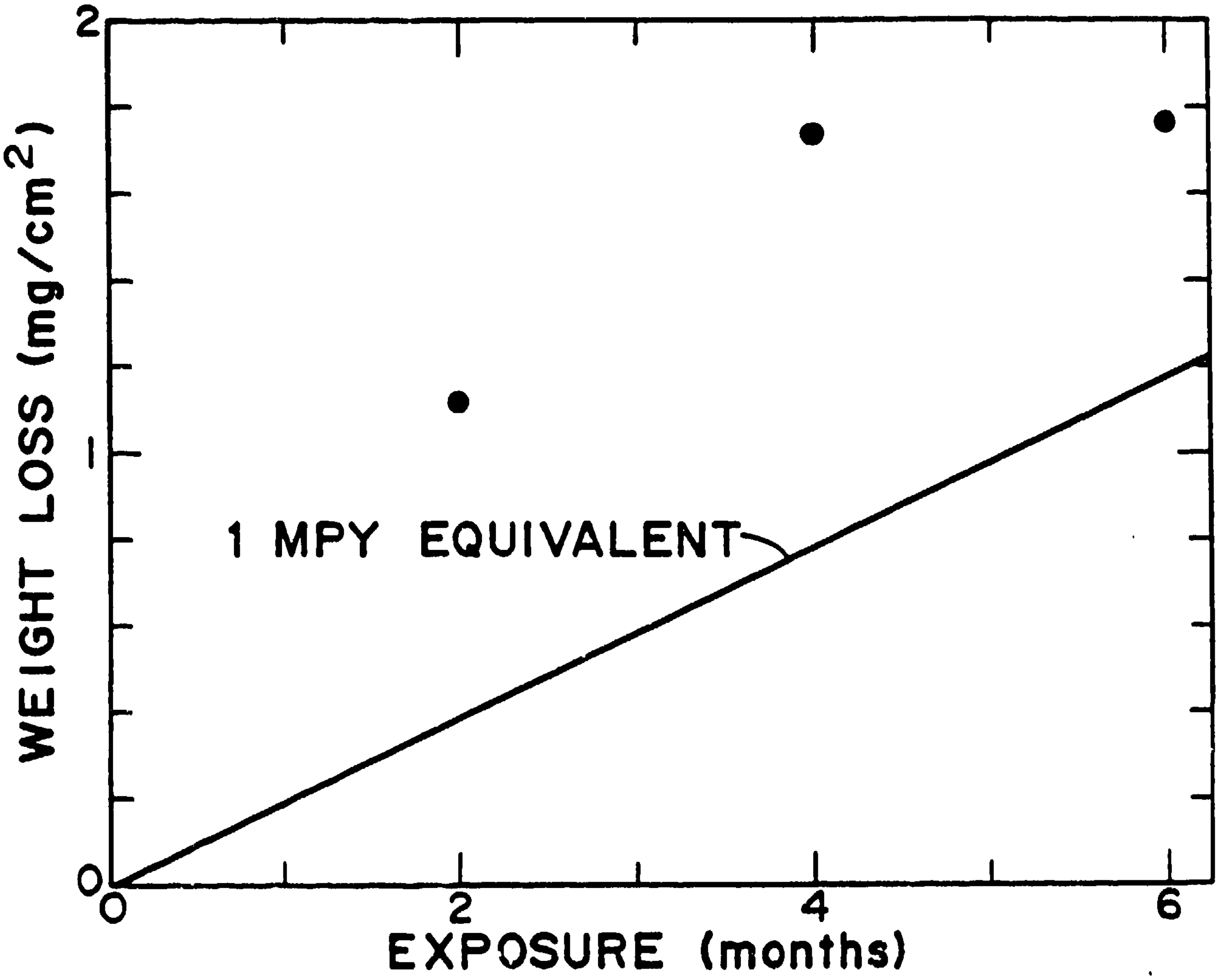

Fig. 5. 1100 aluminum corrosion rate in aluminum/uninhibited-degraded glycol system

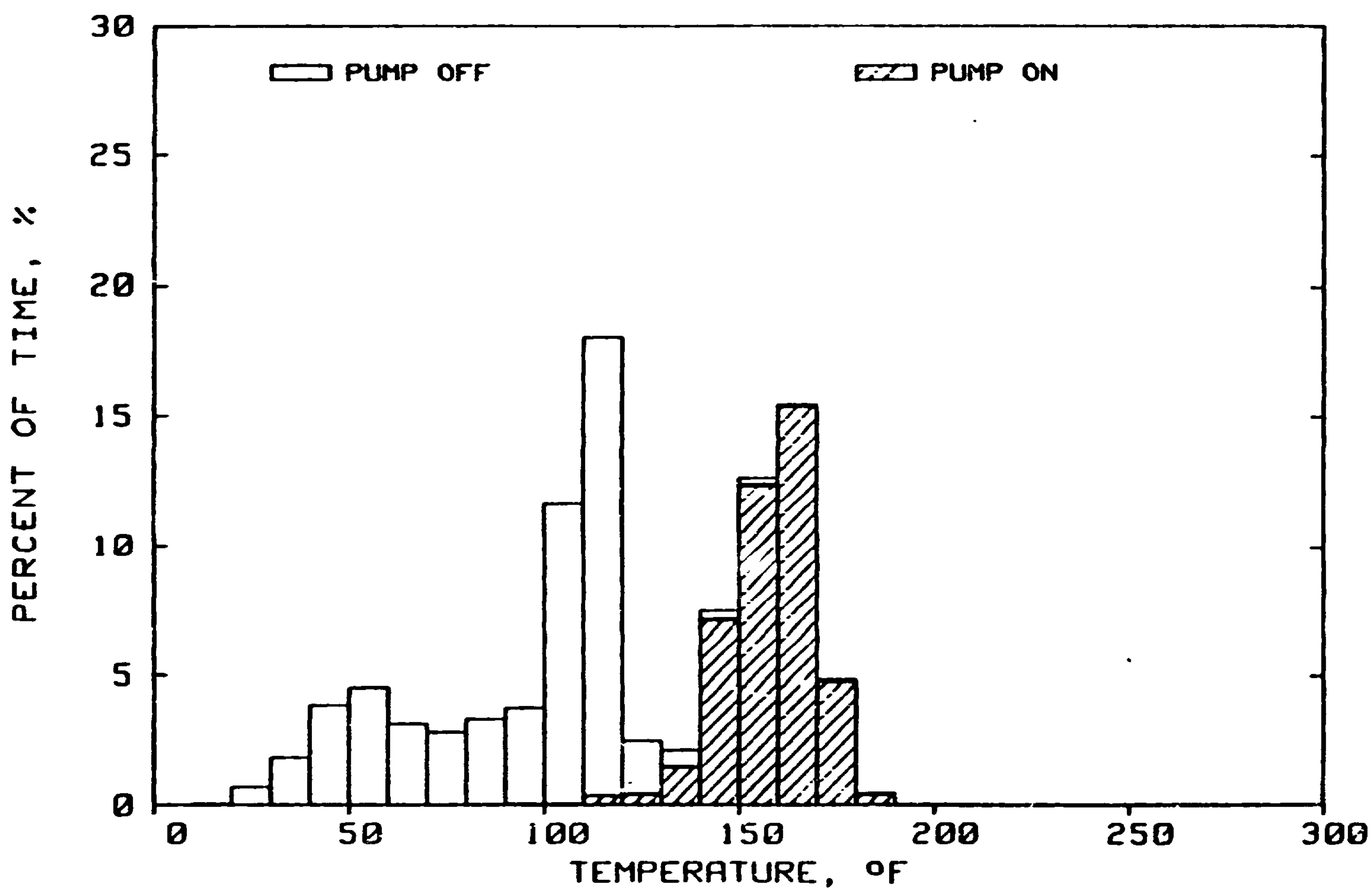

Fig. 6. Operating data for aluminum/uninhibited-degraded propylene glycol system

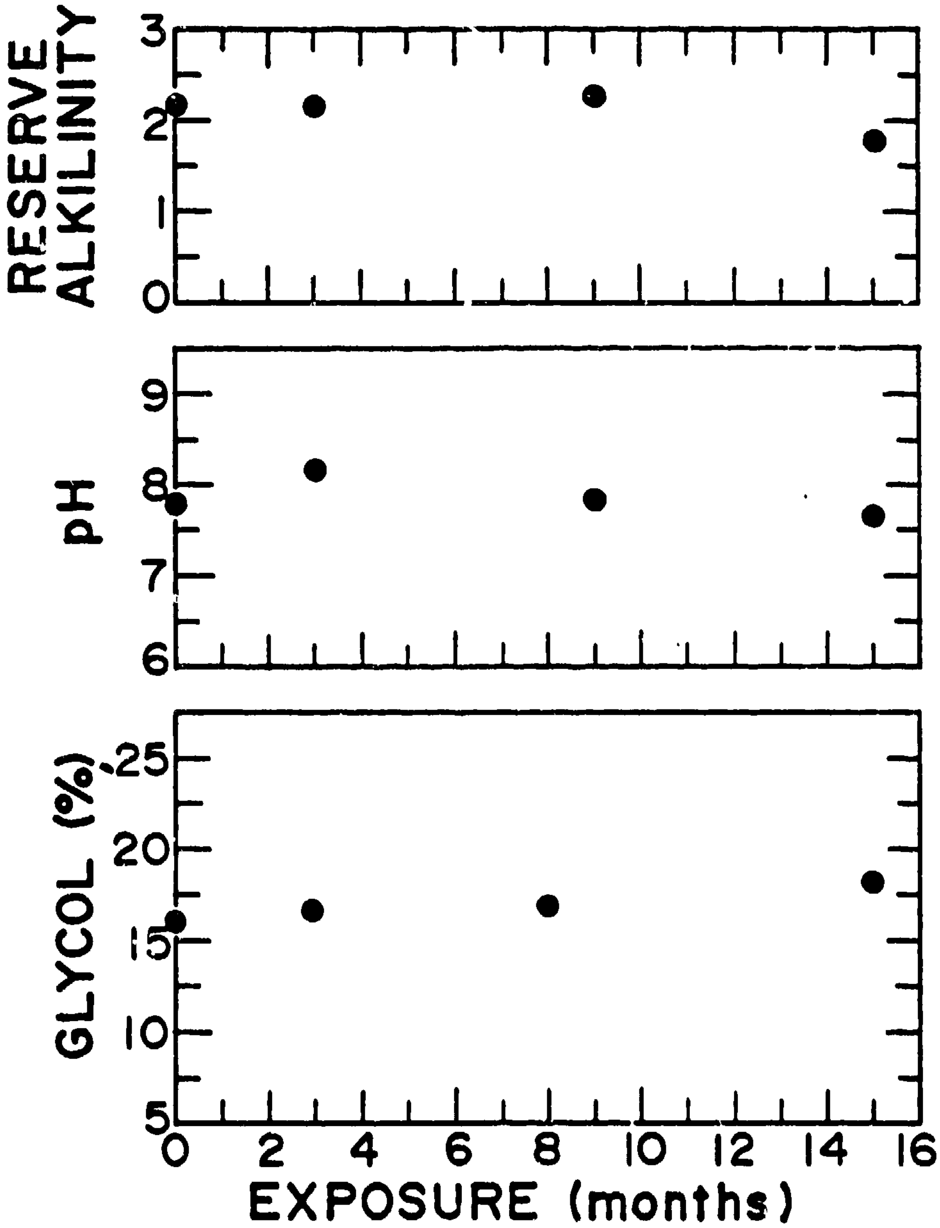

Fig. 7. Fluid data for copper/inhibited ethylene glycol system (Ft. Polk)

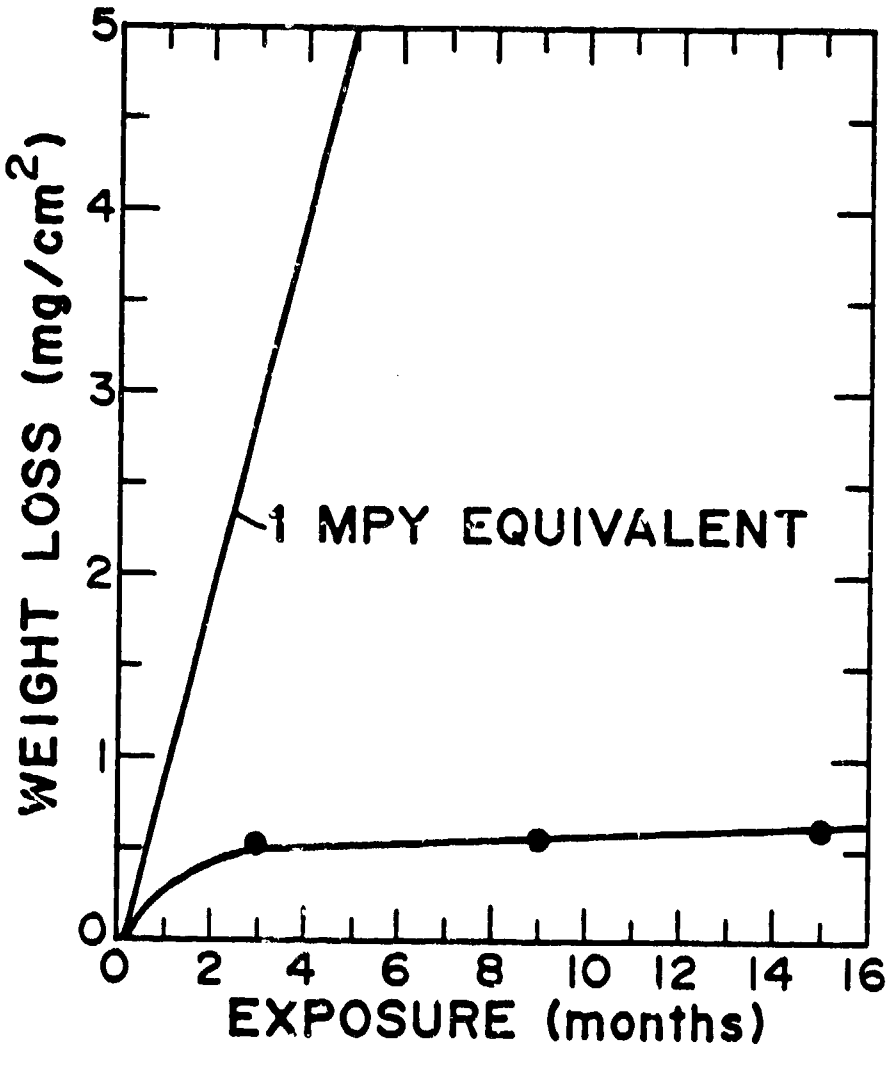

Fig. 8. Copper corrosion rate in inhibited ethylene glycol system (Ft. Polk)

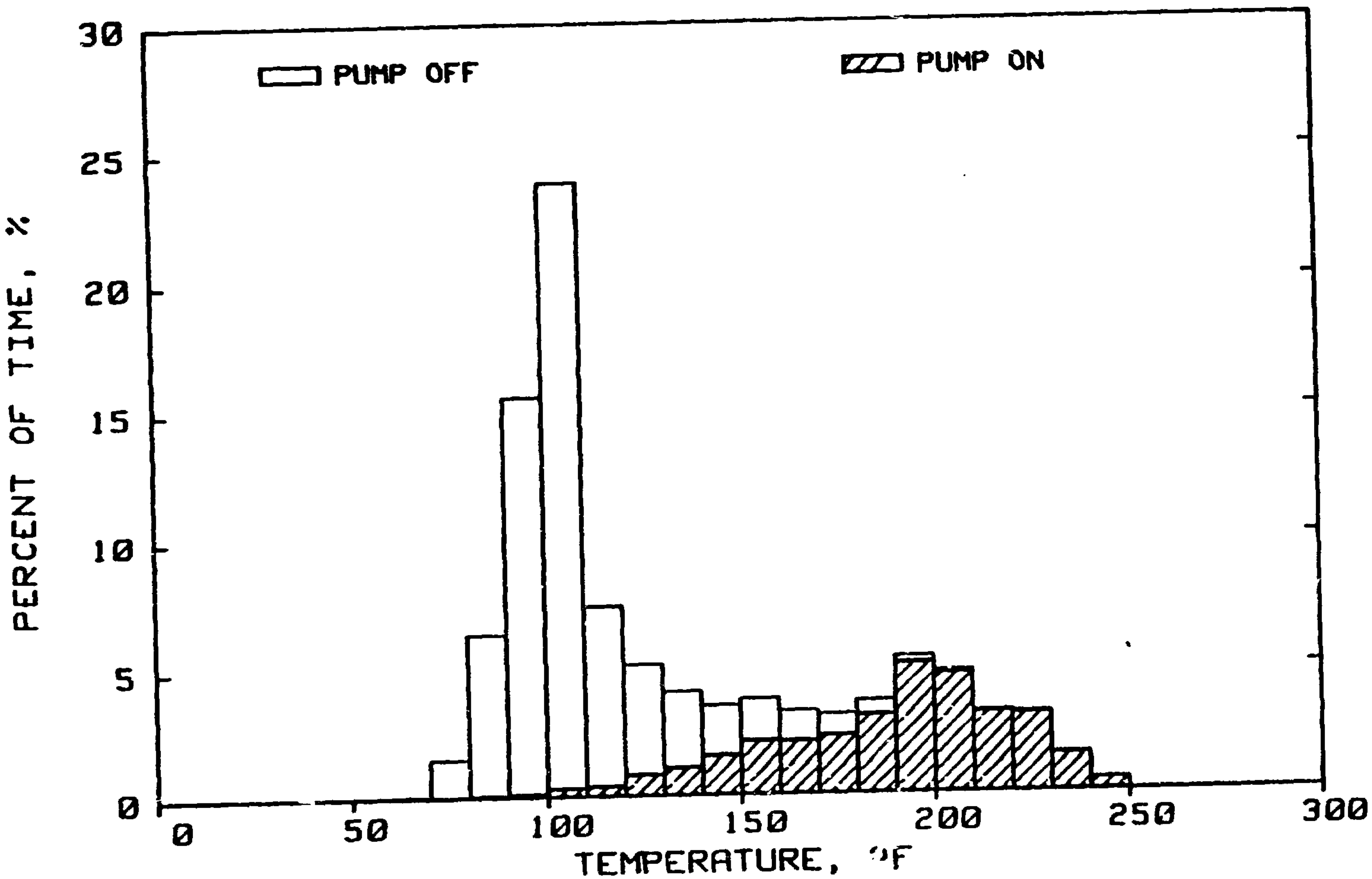

Fig. 9. Operating data for copper/inhibited ethylene glycol system (Ft. Polk)

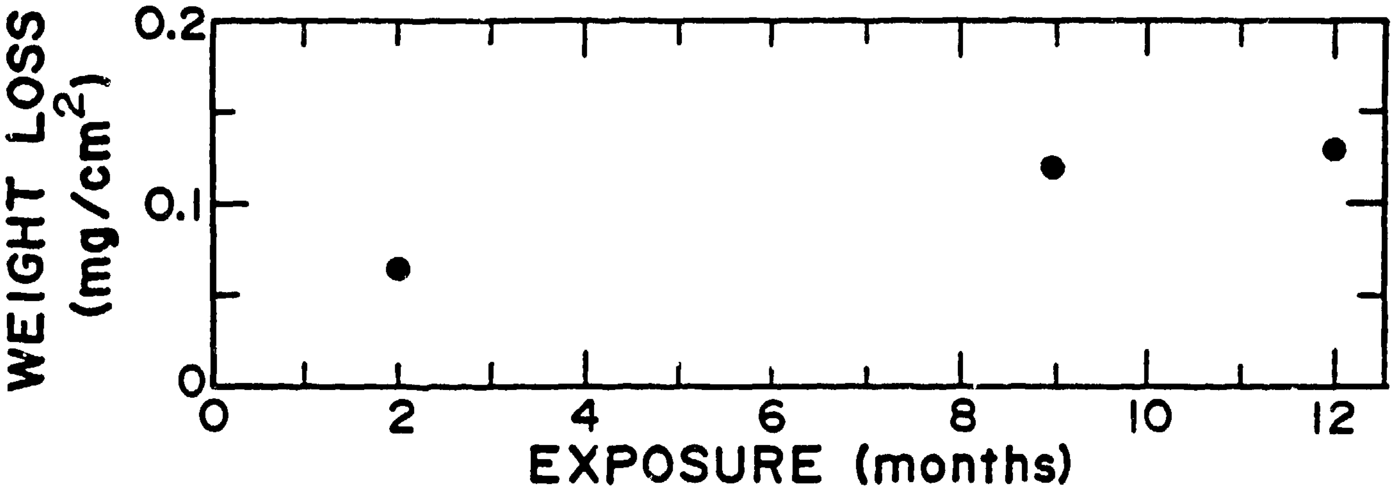

Fig. 10. 444 stainless steel corrosion rate in domestic water system (Nellis BOQ)

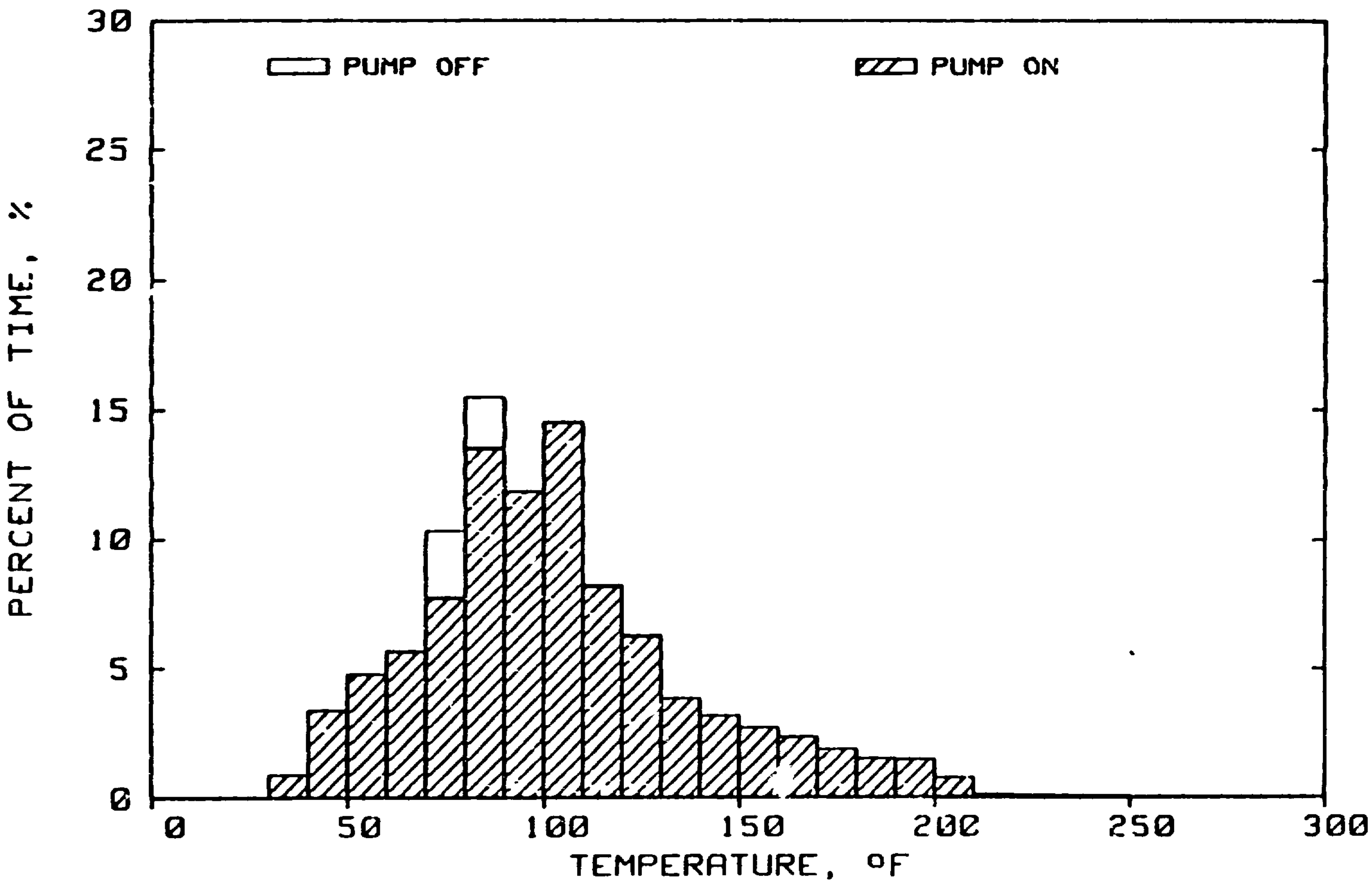

Fig. 11. Operating data for 444 stainless steel/domestic water system (Nellis BOQ)

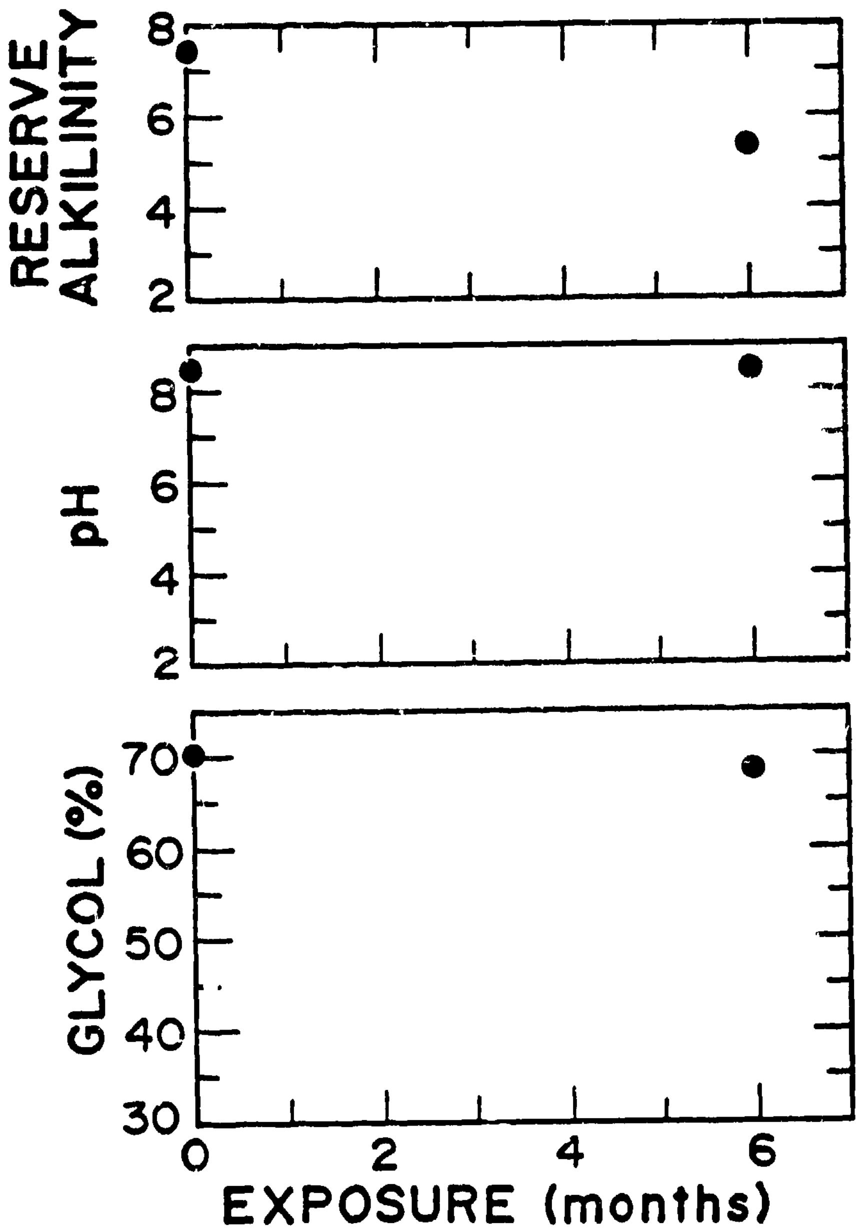

Fig. 12. Fluid data for copper/inhibited propylene glycol system (Otowi)

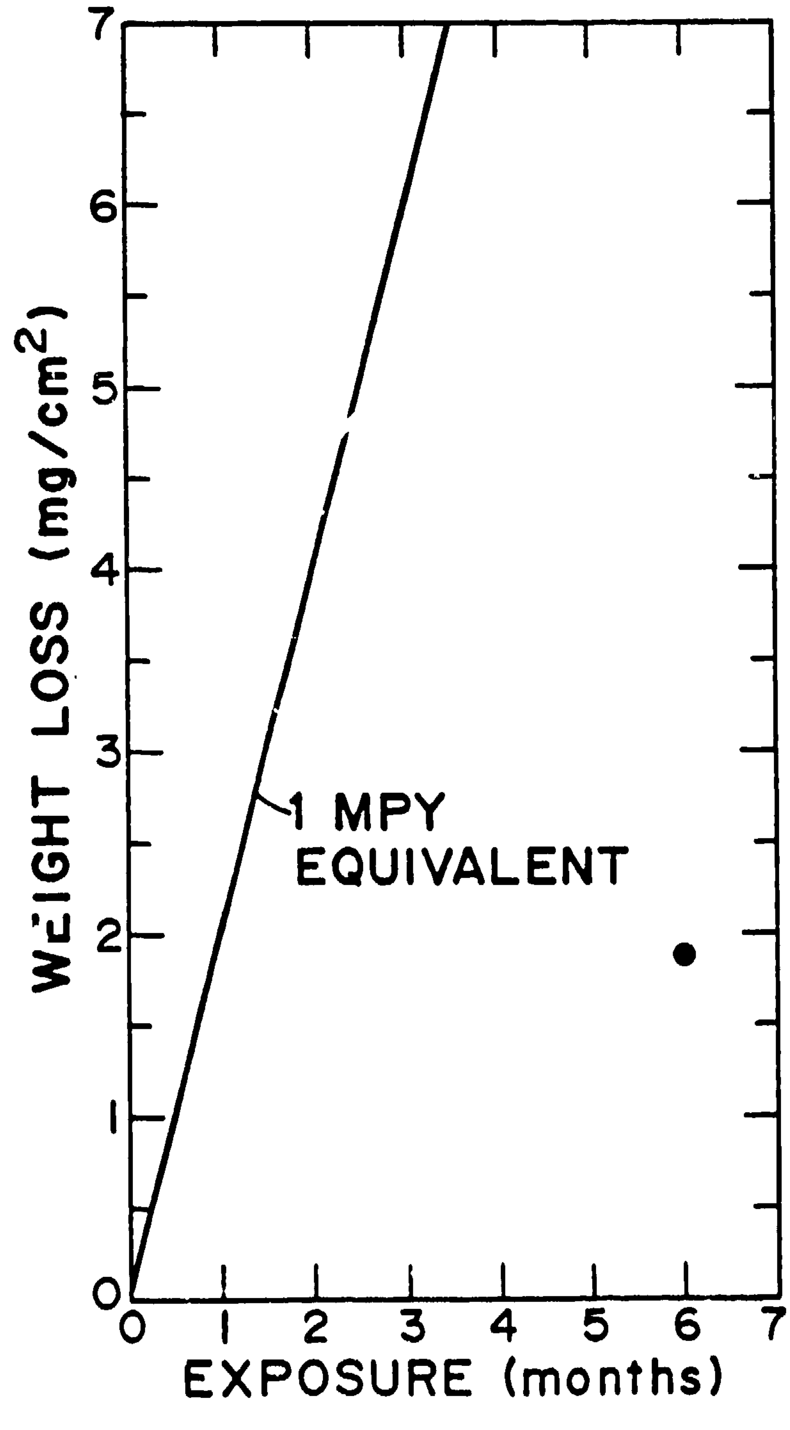

Fig. 13. Copper corrosion rate in inhibited propylene glycol system (Otowi)

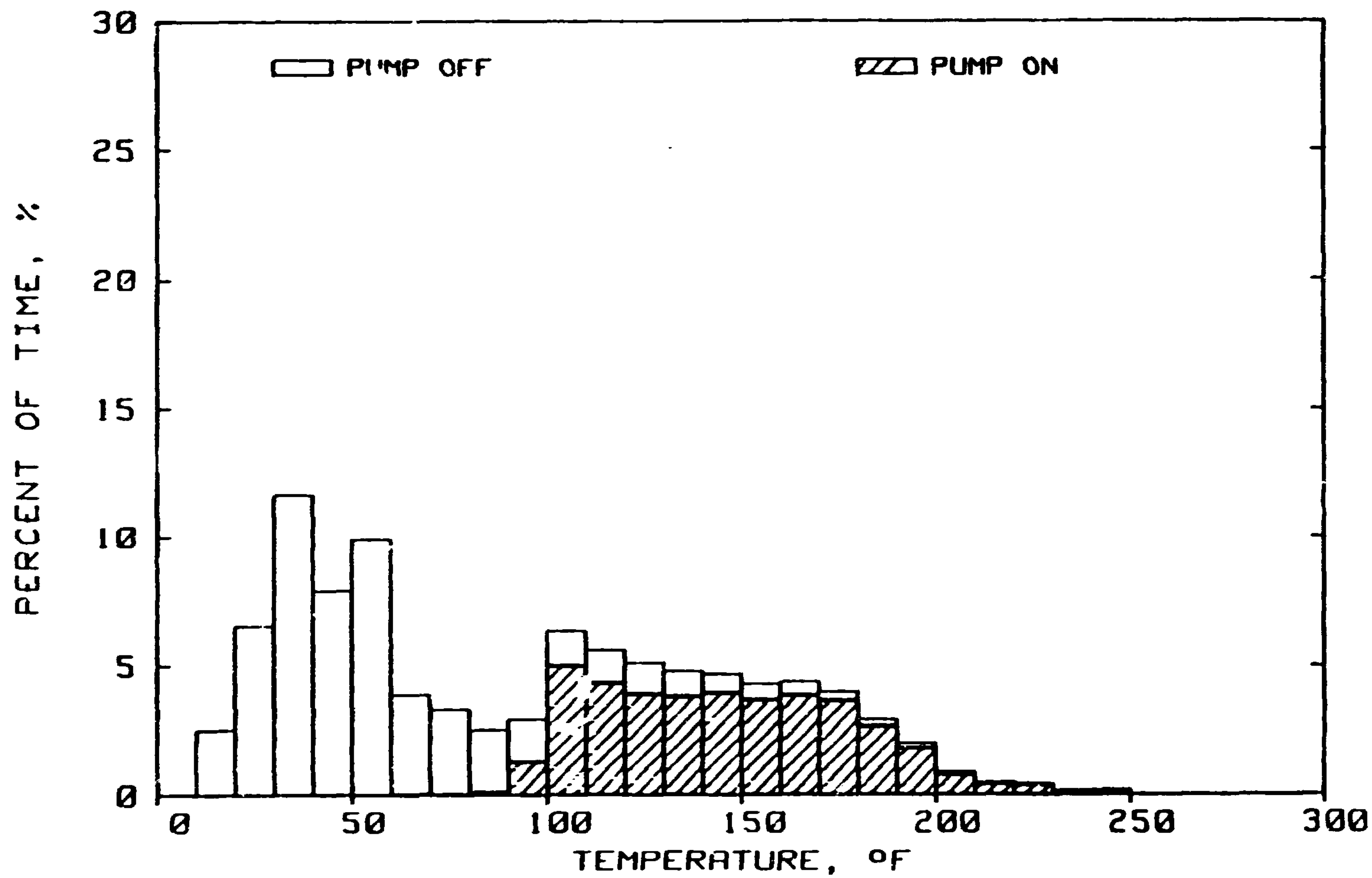

Fig. 14. Operating data for copper/inhibited propylene glycol system (Otowi)

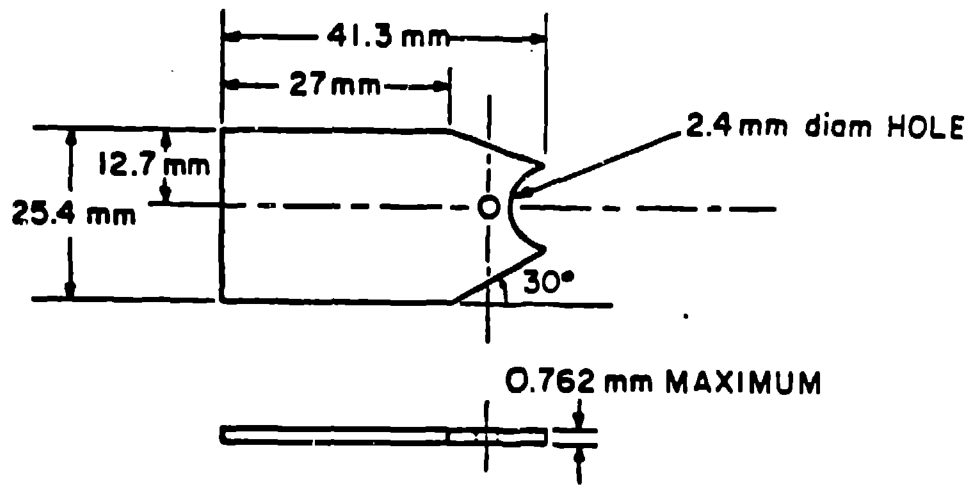

Fig. 15. Simulated solar service test samples

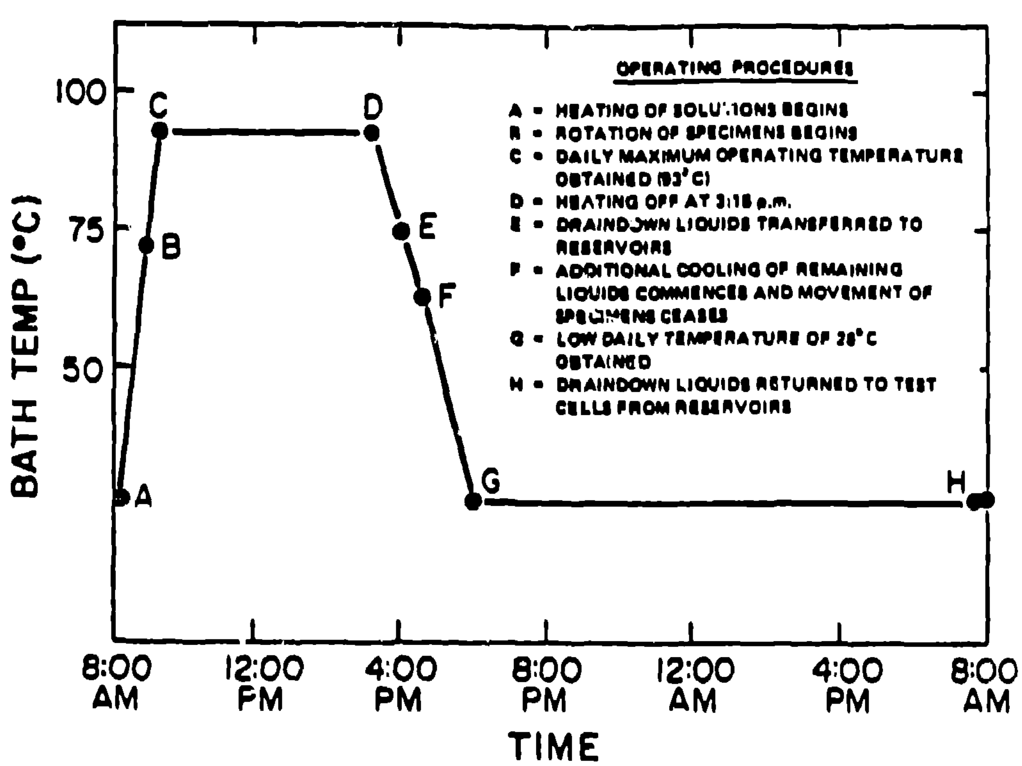

Fig. 16. Daily thermal cycle--simulated solar service test

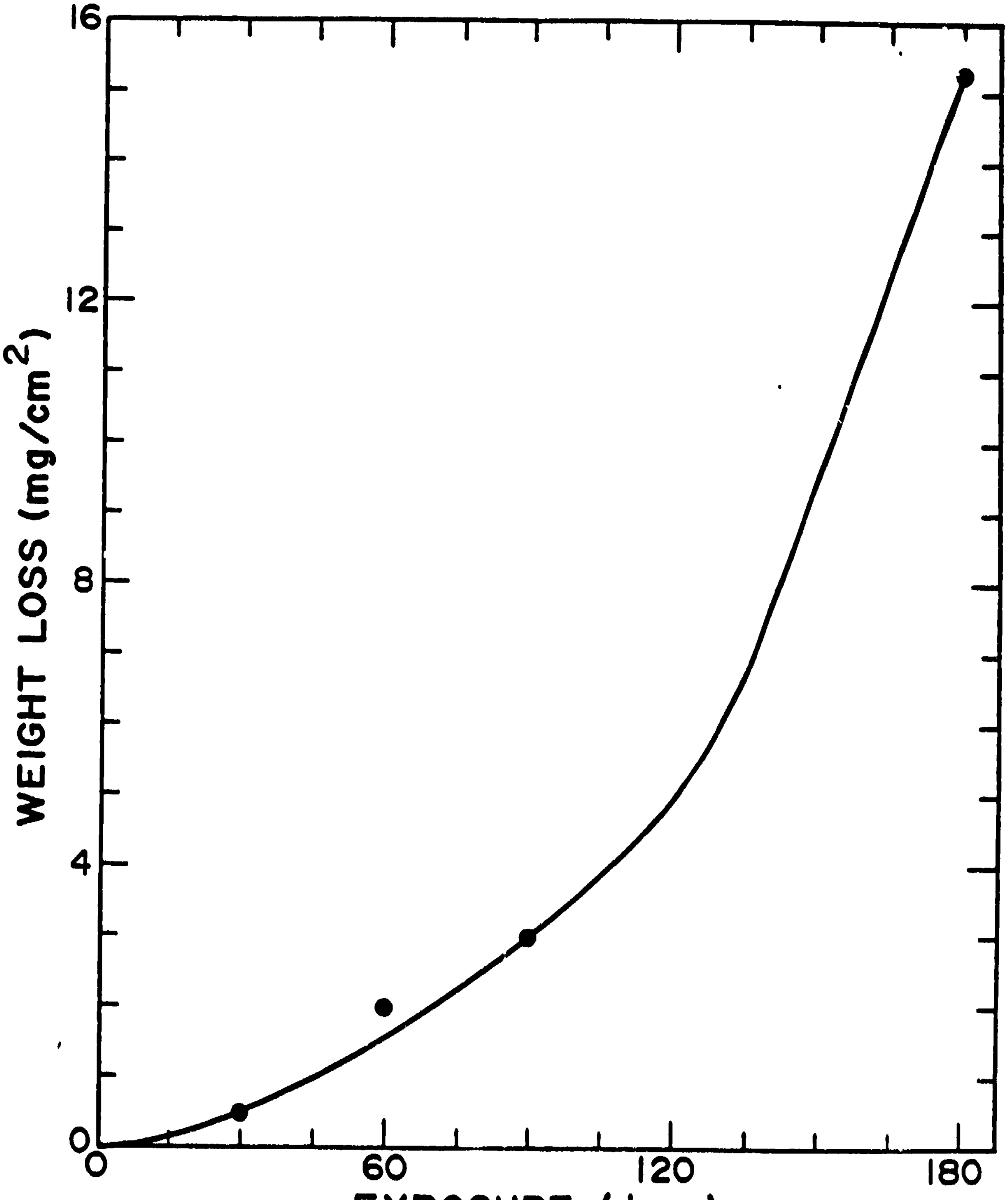

Fig. 17. Corrosion rate of copper in uninhibited degraded propylene glycol in accelerated test

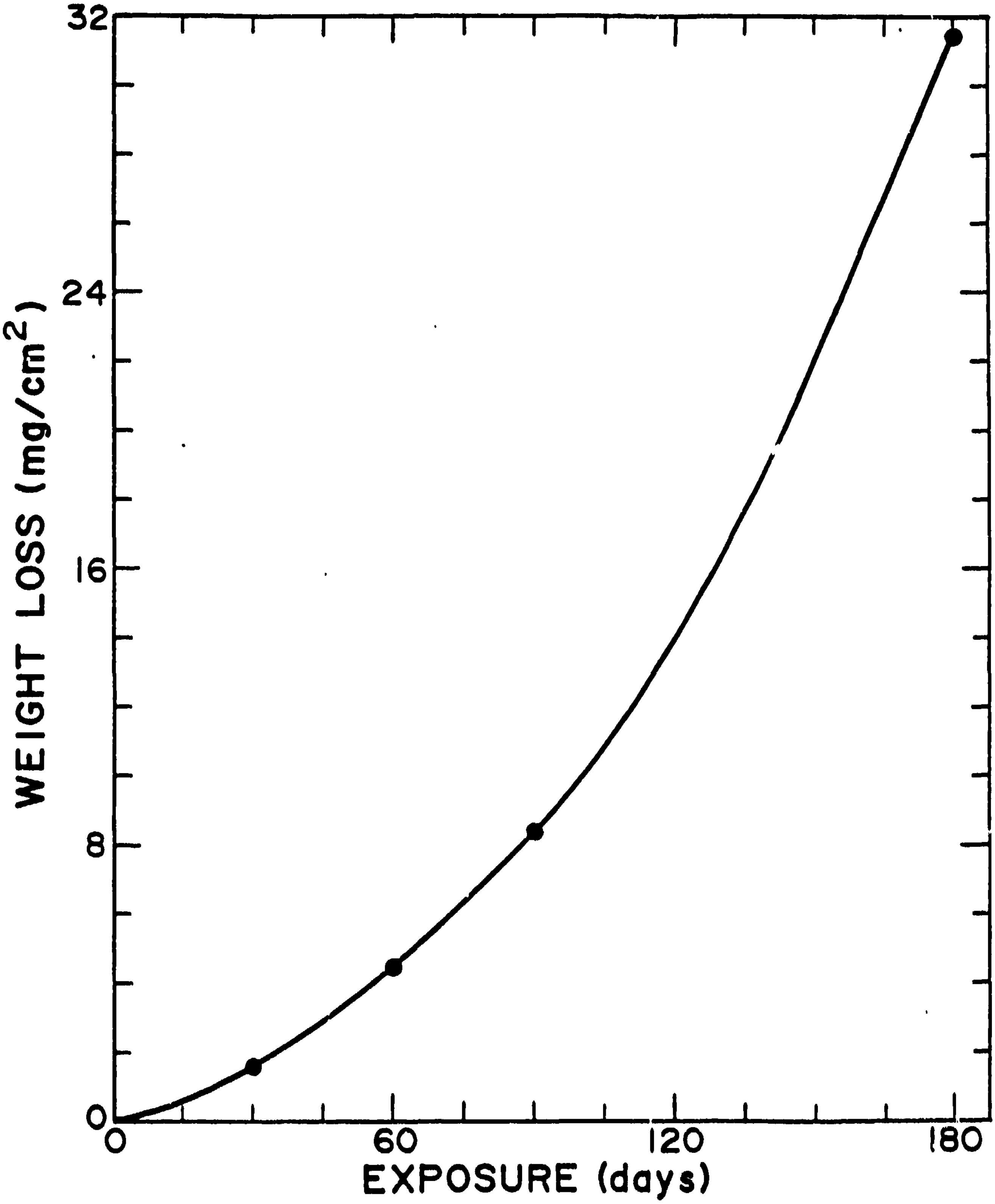

Fig. 18. Corrosion rate of aluminum in uninhibited degraded propylene glycol in accelerated test

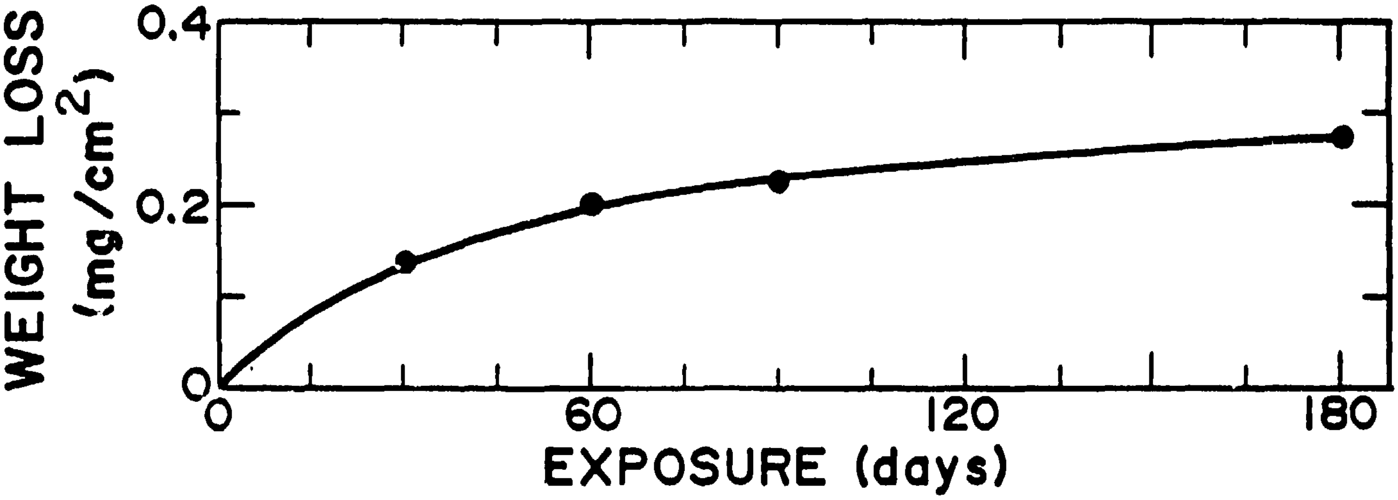

Fig. 19. Corrosion rate for copper in inhibited ethylene glycol in accelerated test

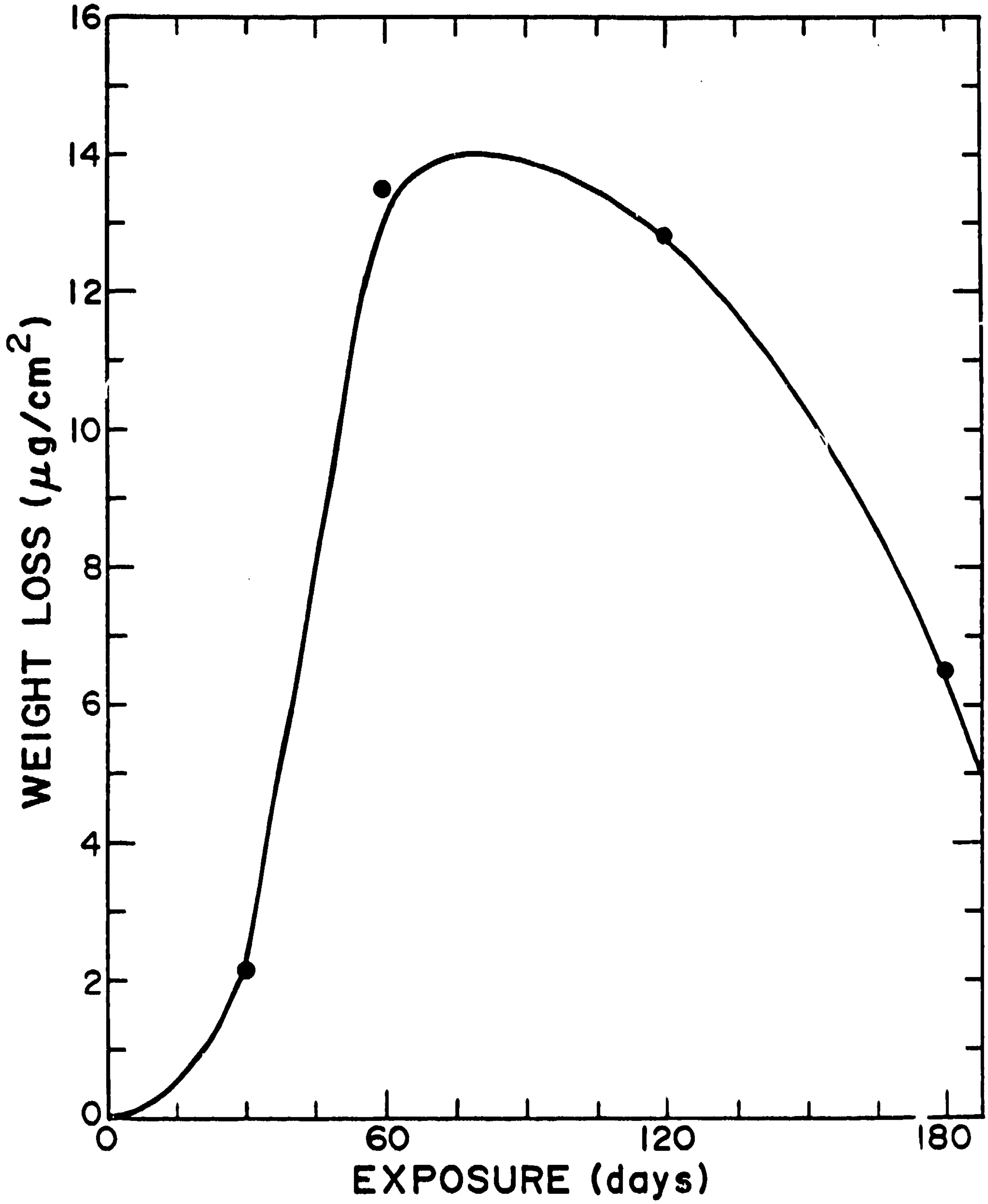

Fig. 20. Corrosion rate of 444 stainless steel in Nellis AFB domestic water in accelerated test

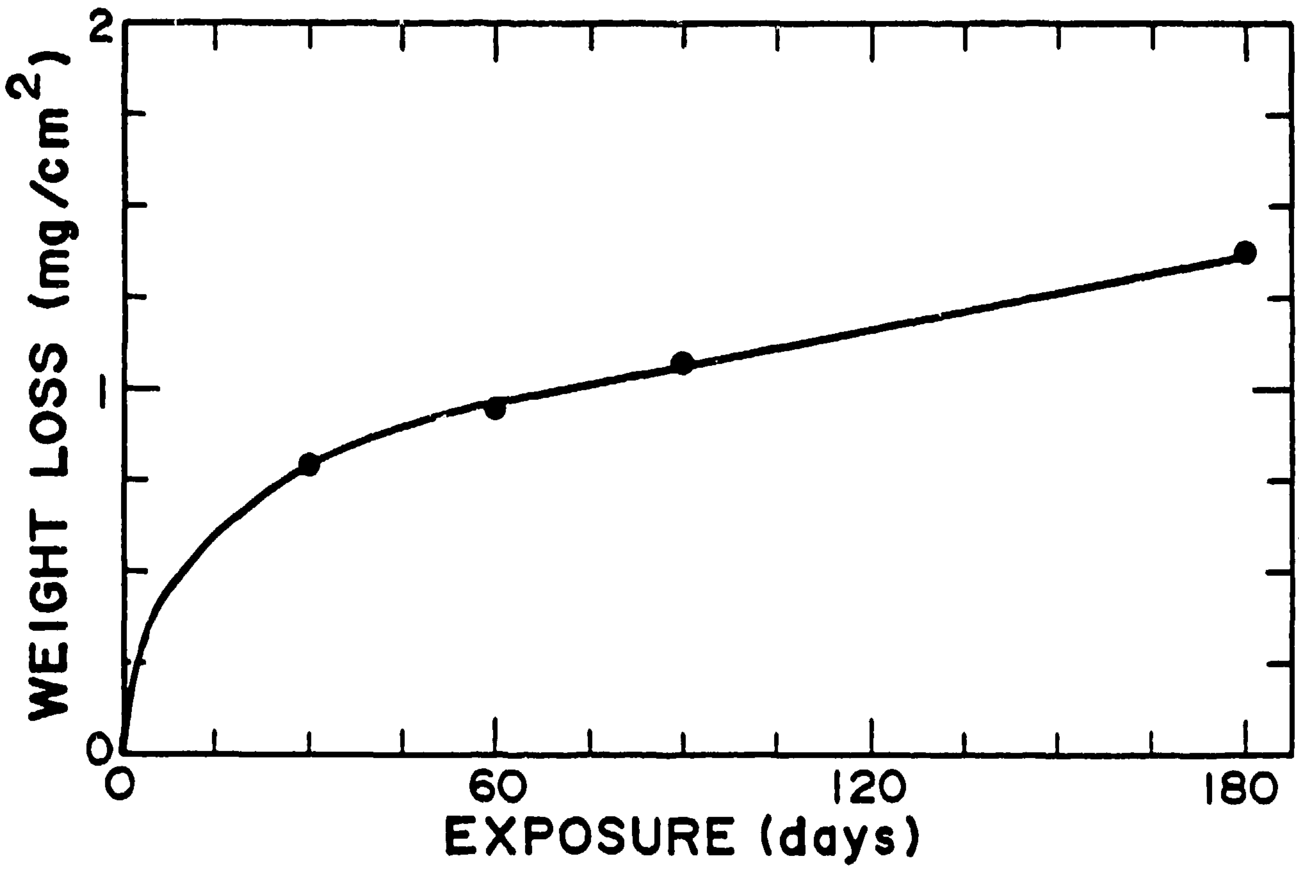

Fig. 21. Corrosion rate of copper in inhibited propylene glycol in accelerated test